Exploitation of Thermal Signals in Tidal Flat Environments

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Award Numbers: N000140710768, N000140810809

LONG-TERM GOALS

The overall goal is to identify and understand the physical processes that shape and change coastal environments. Emphasis is on the application of remotely sensed signals that can be compared with in situ observations and assimilated within predictive models. In tidal flat environments, the major goals are to detect geotechnical properties (e.g., sediment strength), morphologic features (e.g., channels), and related hydrodynamic events (e.g., plumes).

OBJECTIVES

The primary objective of these joint efforts is to develop thermal methods for improved monitoring and prediction of tidal flat environments. Specific objectives are to:

- develop an integrated system for in situ and remote (infrared) measurements of thermal signals in the field, including airborne and fixed platforms,
- test and apply the Lovell [1985] hypothesis for the porosity of sediment as a function of thermal conductivity (lead: Thomson),
- refine methods to estimate inter-tidal bathymetry using sequential waterline detection (lead: Chickadel), and
- explore inverse methods to optimize the assimilation of remote and in situ observations.

APPROACH

The technical approach is to conduct field experiments using simultaneous remote and in situ observations of thermal signals in tidal flat environments (Figure 1). Infrared images collected from airborne and fixed platforms are being used to study surface temperatures, which are then related to an array of interior (sediment and water) temperature measurements. The experiments are designed to study both geotechnical and hydrodynamic aspects of tidal flats.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2008**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Exploitation Of Thermal Signals In Tidal Flat Environments**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Lab,1013 NE 40th St,Seattle,WA,98105**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Code 1 only

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

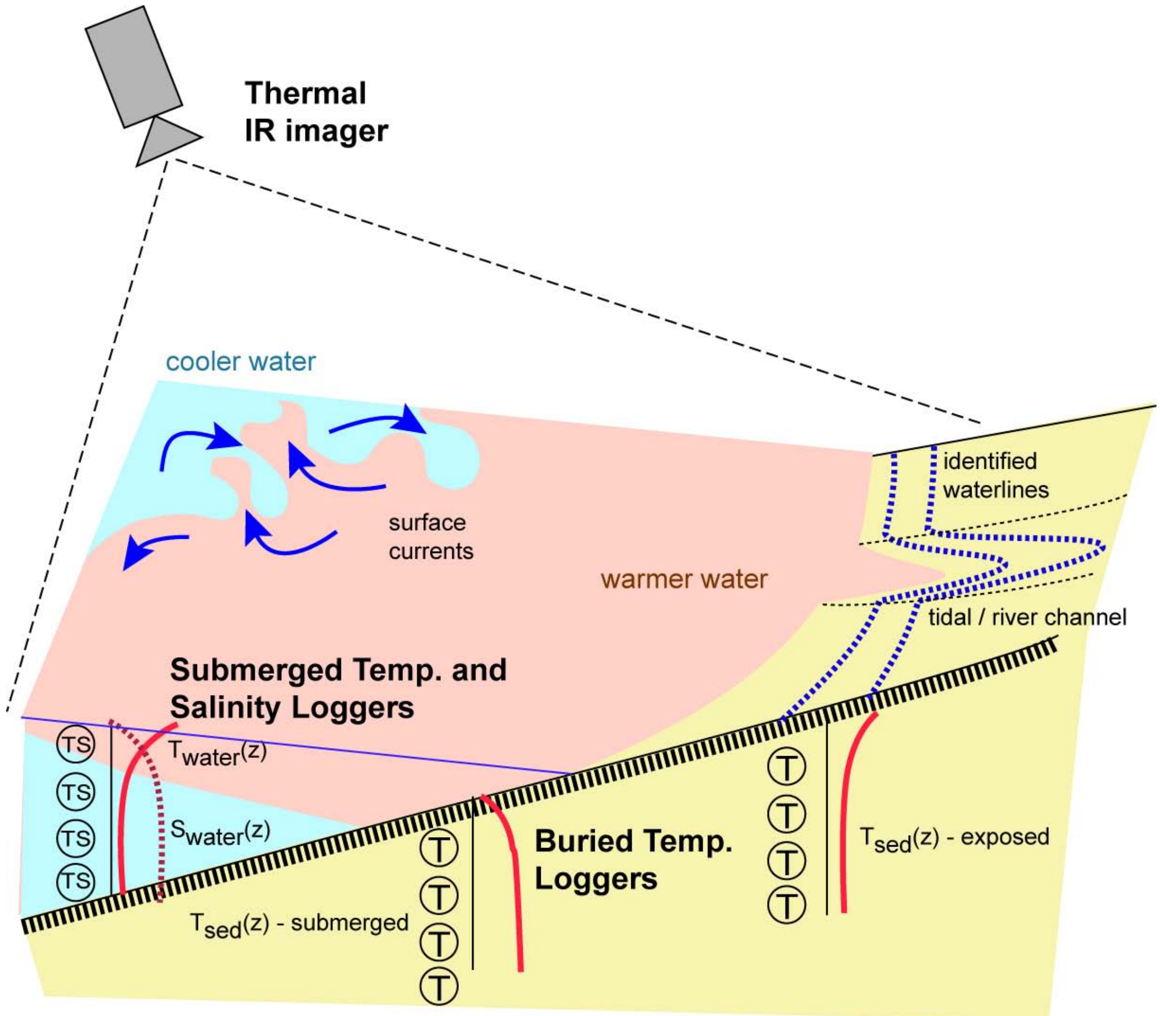

Figure 1. Schematic diagram showing infrared and in situ measurements of thermal signals in a tidal flat environment. The infrared measurements of surface temperature are made from a tower and light aircraft, and the in situ measurements of interior (both water and sediment) temperature are made from anchored platforms.

The sediment temperature data is being analyzed using Lovell's [1985] empirical formula for the fractional porosity *n* (i.e., the water content) of saturated sediments as a function of thermal conductivity *k*, where

$$k = k_s^{(1-n)} k_f^{(n)},$$

and k_s, k_f refer to the thermal conductivities of the solid and fluid, respectively. Assuming a 1D heat balance, the temperature *T* at the surface of the sediment (measured using infrared imagery, see Figure 1) diffuses downward in a vertical *z* profile (measured using buried loggers) at a time *t* rate governed by

$$d^2T/dz^2 = (c\rho/k)\, dT/dt,$$

where *k* is the thermal conductivity of interest, *c* is the specific heat, and ρ is the density [*Subramaniam and Frisk*, 1992; *Jackson and Richardson*, 2002]. Sediment porosity *n* will be

estimated by finding the best-fit *k* at each location in the imagery and then will be compared with sediment samples collected by C. Nittrouer & A. Ogston (University of Washington).

Differential sediment and water surface temperatures are being used to detect waterlines and thereby estimate bathymetry. Waterlines extracted within plan-view infrared images at incremental tide stages will be interpolated to a Digital Elevation Model (DEM), similar to work with optical imagery in the nearshore [*Plant and Holman*, 1997] and infrared satellite imagery [*Ryu et al*., 2002]. Infrared imagery is well suited to shoreline identification due to the differential heating rate of sediment (fast) versus water (slow). We have increased the likelihood for quality data return and the general image resolution over satellite imagery by developing and deploying a small aircraft based thermal imaging system. Flying over the flats in a "lawn-mowing" fashion, we will later georectify and mosaic the collected imagery for quantitative analysis. Bathymetry estimates will be compared against ground surveys collected during the pilot experiment.

The field data also will be used to quantify surface fluid velocities (e.g. using imagery [*Holland et al.*, 2001]) and estimate volume transport (using in situ data [*Wunch*, 1996]). These hydrodynamic quantities will be used to evaluate correlations with bathymetric features, such as channels, and will be compared with velocity measurements by S. Elgar & B. Raubenheimer (Woods Hole Oceanographic Institution).

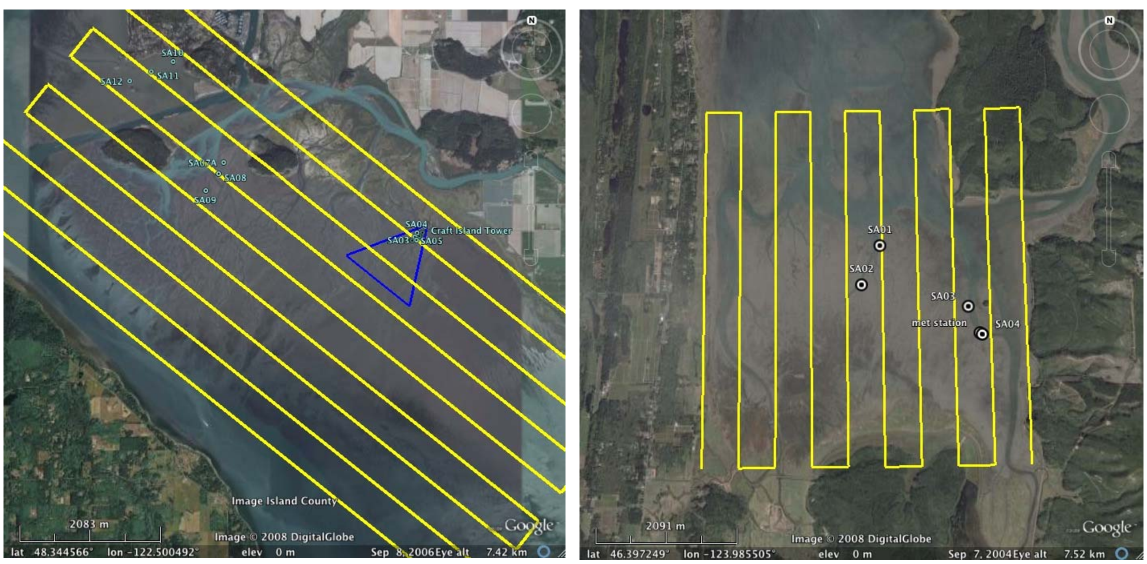

Figure 2. Google Earth images showing instrument locations (dots), overflight tracks (yellow lines), and tower field of view (blue triangle) during FY08 field experiments on the Skagit (left) and Willapa (right) Flats.

WORK COMPLETED

During the first part of FY08, we developed and test tower and airborne imaging systems for remote locations. During the second part of FY08, we successfully (99% data return) these and other insturments in pilot field experiments on the Skagit and Willapa Flats of Washington State (Fig. 2). In addition to the primary measurements of temperature and pressure, a metreological station and two

accoustic Doppler current profilers were successfully deployed. The data set includes a range of conditions and spans the transition from diurnal to semi-diurnal tides, as summarized in Fig. 3.

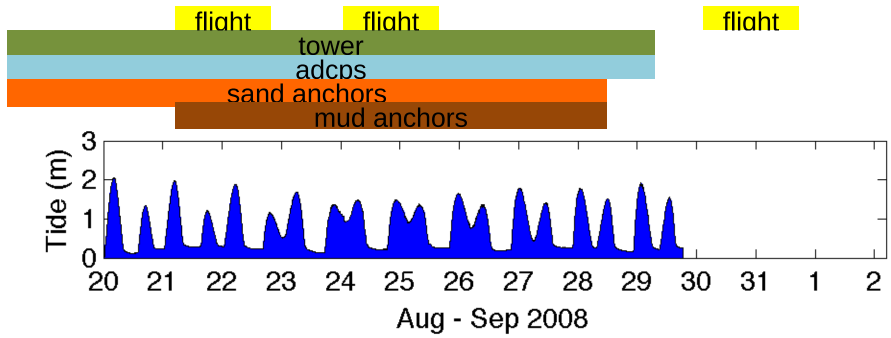

Figure 3. Skagit Data summary.

RESULTS

Preliminary data analysis suggests that thermal signals can be used to remotely classify sediments and detect bathymetric features. Fig. 4 compares the thermal response of sandy sediments with that of muddy sediments on the Skagit Flats. Each location is exposed to solar radiation at low tide, and the net heat gain is conducted to depth. The sandy sediments have a much stronger response to heating, because the water content and porosity is lower, compared with the muddy sediments. Preliminary application of the Lovell formula indicate porosity values of 42% and 60% for the sandy and muddy sediments, respectively. This is consistent with qualitative evaulation of the Skagit Flats, where the sandy areas are firm and easy walking, compared with the muddy areas which are soft and difficult walking. Work is ongoing to related the in situ conduction to the remote (infrared) sensing.

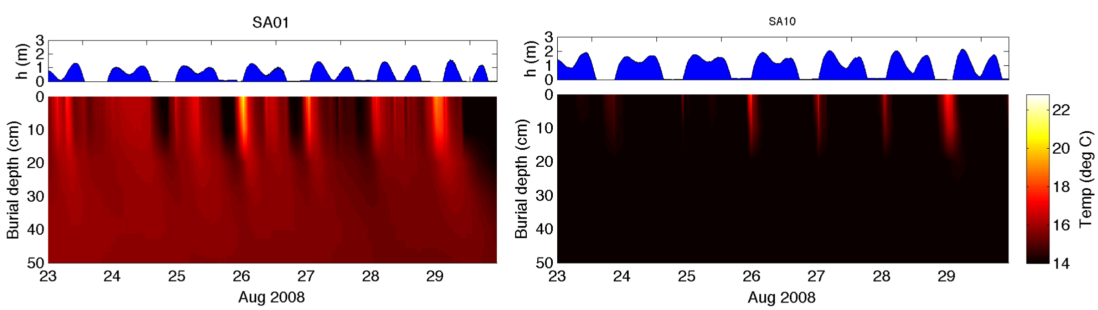

Figure 4. Examples of vertical temperature profiles in sandy (left) and muddy (right) sediments on the Skagit Flats. The surface is heated during low tide exposure, and the subsequent response is a function of the porosity.

Thermal images collected from overflights showed substantial gradients which can be exploited to measure large-scale bathymetry and circulation. Example thermal images, shown in Figure 5, demonstrate the thermal signatures observed during the flights on 2008 Aug. 23 during mid-flood tide. The sharp river plume front observed during this time was particularly exciting, and provides encouragement for our goal to identify and map the evolution of the river plume with tidal and seasonal changes. Thermal deliniations between water and exposed flats is also strong on the Skagit, as

demonstrated by th reasonable sample waterline (Figure 5) found through a simple thresholding technique. Future work will focus on automated georectification of the aerial images and preliminary mapping via a large-scale mosaic. Developmnent of robust techniques to identify waterlines and thermally distinct surface water masses is underway. Monthly overflights for the coming year are planned for Skagit flats to capture seasonal changes, and a single revisit to Willapa flats next year is planned.

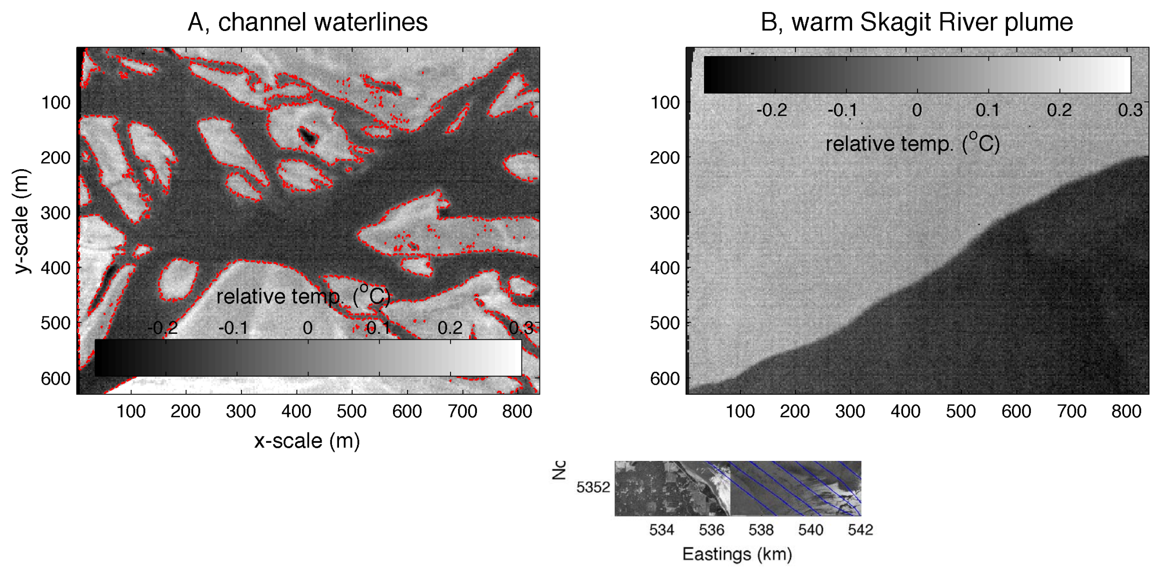

Figure 5. Sample thermal images of exposed channel and identified waterlines (left) and the warm Skagit River plume (right) demostrate the strong thermal signals observed on the Skagit flats. Locations of the images and flight lines (blue) on the flats are shown (inset).

IMPACT/APPLICATIONS

Improving techniques to remotely quantify tidal flat properties will allow for real time monitoring and safe operation in these environments. In particular, remote porosity estimation and channel detection will improve navigation for amphibious landings. In addition, the development of techniques to assimilate remote and in situ measurements will facilitate the testing of predictive models.

RELATED PROJECTS

A new imaging system, developed under a DURIP (PI: Andrew Jessup), will improve spatial coverage in future field experiments (planned for FY09) by using a “helikite” to gain elevation and dwell time.

An ongoing MURI (Coherent Structures in Rivers and Estuaries Experiment, PI: Andrew Jessup) has provided infrared image data for proof of concept applications in the remote sensing of tidal flats (www.cohstrex.apl.washington.edu). Equipment and resources are shared with this project.

This effort is a contribution to the Tidal Flats DRI (www.tidalflats.org).

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HONORS/AWARDS/PRIZES

ONR Young Investigator Program (N000140710768): Jim Thomson, Applied Physics Lab, University of Washington.